Reply to "Reexamination of the small-angle neutron scattering data on concentrated AuFe spin-glasses"

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We address Murani's criticism of our previous interpretation of his neutron scattering experiments in spin-glasses. We analyze the data that he presents in the previous comment and refute his claims.

In a previous paper[1] we demonstrated in two different ways that Murani's small-angle neutron scattering data[2] on spin-glasses were consistent with the notion that these materials undergo a sharp phase transition at a single ordering temperature T_{sg}. Both of these arguments incorporated the observation that the total cross section $I(q,T)$ is a sum of the susceptibility term $T\chi(q,T)$ and the "Bragg" term $I_B(q,T)$.

Our first approach was based on a data analysis in which we showed that it is possible to choose smooth Bragg curves which when subtracted from $I(q,T)$ lead to a susceptibility which has a single maximum at T_{sg}. The second approach showed that in an Edwards-Anderson[3] (EA)-like mean-field theory of the phase transition, one would deduce that the maximum in the total cross section was shifted to a q-dependent temperature below T_{sg}, as Murani finds. Therefore, his observation of q-dependent maxima is not unexpected.

In the above comment[4] Murani levels four criticisms of our work [labeled (a)−(d)] which we believe can be easily answered.

(a) We argue that it is inappropriate and misleading to refer to the maximum in $\chi(q,T)$ at T_{sg} as an "artificially created anomaly." Indeed, it is a consequence of our assumption that the Bragg curves (which are essentially the Fourier transform of the EA order parameter) behave like an order parameter and therefore vanish at T_{sg}. Our point was to demonstrate that applying this assumption to the data leads to the conclusion that his measurements are consistent with a sharp freezing transition. This result is not a necessary consequence of our assumption and therefore should not be viewed as "artifi-

cial." That is, it was entirely possible that, given a reasonable value of T_{sg}, the maximum in $\chi(q,T)$ could still have been q dependent. What is most significant is that this turned out not to be the case.

(b) We have found, using somewhat different forms for the smooth Bragg curves, than does Murani,[4] that there are no shoulders in $\chi(q,T)$ for the cases he considers. This is illustrated in Figs. 1 and 2 for the 13 and 15% alloys, respectively. The left column in both figures shows Murani's analysis of the same data [labeled (e)−(h) of Figs. 2 and 3 in his paper]. Our results are in the right-hand columns. Choosing slightly more sharply rising (at T_{sg}) Bragg curves completely eliminates his "shoulders," within the noise of the data, for both concentrations. We make two further points. (1) Note that the raw data that he presents are not smooth. In the total cross section there are small "shoulders" for $T > T_{sg}$ and "dips" both above and below T_{sg} which are in many cases comparable to the "shoulders" in $\chi(q,T)$ he finds for $T < T_{sg}$. (2) The forms which are factorizable in the q and T variables, which he uses for the Bragg curves [see Eqs. (1) in Ref. 4] are *not* consistent with our mean-field theoretic calculations [see Eq. (10) in Ref. 1]. These provide unnecessarily severe constraints on the allowed shape of the Bragg curves. On the basis of all of the above points, it is argued that there is insufficient evidence to support the claim that the shoulders in $\chi(q,T)$ are real.

(c), (d) It is clear that our random-phase-approximation theory cannot reproduce all of the detailed features of the data. Our calculation leads to broader maxima and to small anomalies at T_{sg} for very small q in $I(q,T)$ which are not observed exper-
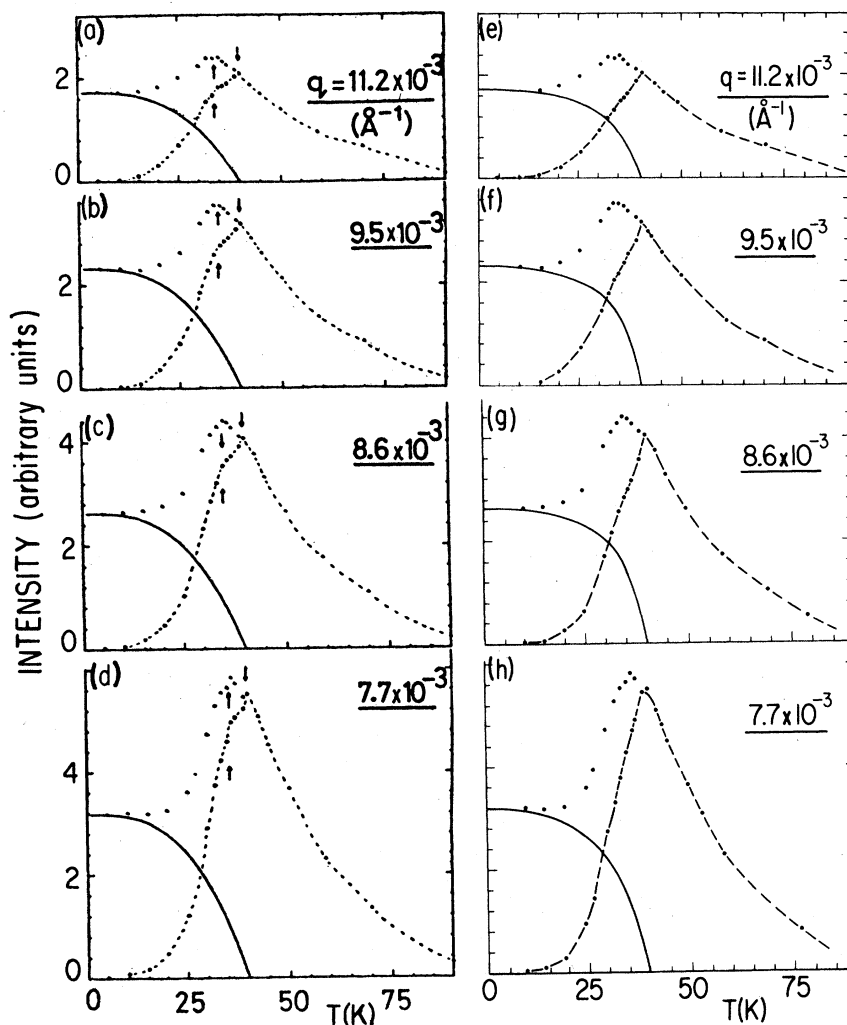
FIG. 1. Small-angle scattering intensity for an Au-13 at.% alloy. The dotted curves are experimental results (after Ref. 4). The solid curves are estimations of the Bragg term and the dot-dashed curves $TX(q,T)$. The left-hand column reproduces Murani's results [labeled (e)−(h) in Fig. 2 of the preceding paper]. The right-hand column represents the present work.

imentally. We do not believe these two shortcomings reflect in any essential way on the physics of our theory. They are most likely consequences of our calculational techniques. It is important to re-emphasize that our direct calculation makes the essential and important point that, even in the simplest mean-field theory of the spin-glasses, we would expect to see a q-dependent shift in the temperature of the maximum of the total cross section.

In answer to Murani's remarks on the limitations of our cluster mean-field theory,[5] we point out that

choosing our clusters to have a fixed size is not incompatible with the notion that there is a continuous evolution of spin correlations in spin-glasses. Because we treat the internal dynamics of the cluster exactly (so that our clusters are not rigid entities) the intracluster (as well as the intercluster) correlations are very temperature dependent. This is the whole reason why our model yields qualitative agreement with C_v and $I(q,T)$ data.

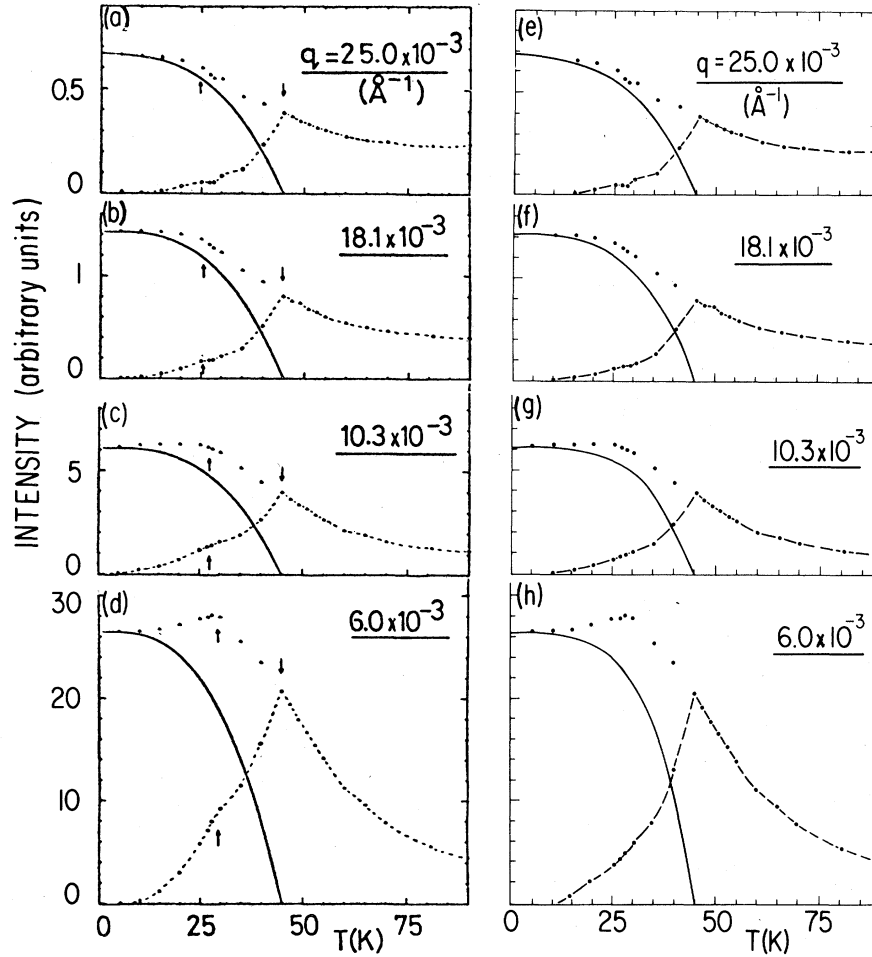In summary, our previous theory and data analysis of the neutron cross section[1] in spin-glasses appears

FIG. 2. (a)—(h) Neutron scattering intensity for an Au-15 at.% alloy. The left-hand column reproduces Murani's results [labeled (e)—(h) in Fig. 3 of the preceding paper]. The right-hand column represents the present work.

to be sound. We cannot prove from the data that there is a sharp phase transition or that there are no q-dependent anomalies in $\chi(q,T)$. However, we can claim that all the data we have investigated are consistent with the notion that there is a sharp phase transition (as "seen" by neutrons) in these materials.

[1]C. M. Soukoulis, G. S. Grest and K. Levin, Phys. Rev. Lett. 41, 568 (1978).
[2]A. P. Murani, Phys. Rev. Lett. 37, 450 (1976).
[3]S. F. Edwards and P. W. Anderson, J. Phys. F 5, 965 (1975).

[4]A. P. Murani, Phys. Rev. B 22, 3495 (1980) (preceding paper).
[5]C. M. Soukoulis and K. Levin, Phys. Rev. Lett. 39, 581 (1977); Phys. Rev. B 18, 1439 (1978).